

# SCREENING OF POLYMERS TO DETERMINE THEIR POTENTIAL USE IN EROSION CONTROL ON CONSTRUCTION SITES

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The purpose of this research as a part of the urban component of the Lake Mendota watershed is to produce a practical and reliable erosion control alternative to the sediment delivery from new urban areas to be developed in the watershed. The use of soil erosion inhibitors are an innovative solution to the sediment entering the receiving water in watershed due to changes in the hydrology of the watershed due to changes in land use.

The major sources of sediment include: eroding agricultural lands; eroding streambank; erosion from developing urban areas; and sediment from established urban areas. The sediment moves to the receiving waters by rainfall runoff and snow melt. The result of urbanization in the Lake Mendota Priority Watershed will cause an excess of stormwater runoff delivered to the waterways due to the increase in efficiency in the delivery systems through pipes and channelized flow causing excessive stormwater flow.

Runoff from urbanizing areas is a major source of sediment when large

areas of soil are exposed to the erosive powers of rainfall and concentrated flow. The consequences of inadequate construction site erosion control is catastrophic due to the large amounts of eroded soil deposited on streets, suspended solids in rivers and flowing waters and deposited in marshes and lakes.

The urbanization process of a watershed increases the percentage of impervious area. The increase in impervious areas impacts the stream hydrology due to the increase in runoff volume over a short period of time. The reduction in concentration time creates large increases in stream peak flow and flow volumes when compared to natural streams. These sudden increases above normal and decreases below normal during and after a rainstorm produce streams with high sediment load and streambank erosion which limit aquatic life and recreational uses.

Water soluble polymers, generally described as polyacrylamides (PAMs), appear to have a variety of beneficial soil amendment properties including minimization of water runoff, erosion and crusting, and stabilization of soil structure.

The objective of this evaluation was to determine the effects of anionic, cationic and nonionic polyacrylamides (water soluble polymers) on soil aggregation stability and rate of settling in free movement of soil particles. This report presents the evaluation of 22 polyacrylamides (polymers). Polymers were evaluated according to aggregate and settling times' criteria. The methods used for screening the polymers were: the wet Sieving Technique and the Sedimentation rate.

## Literature Review

Soil physical characteristics like structure, texture, porosity, and water retention have been recognized as important in determining soil readability, infiltrability and runoff potential. Since the pioneering work of Duley (1939) many studies have demonstrated the significant influence of these factors on surface sealing which causes decreased infiltration, delayed or reduced plant emergence and increased erosion (Rubin 1966, Segimer and Morin 1970, Callebaut et al. 1986, Ronkens et al. 1990, LeBissonnais 1970). The structural sensitivity of soils and the iden-

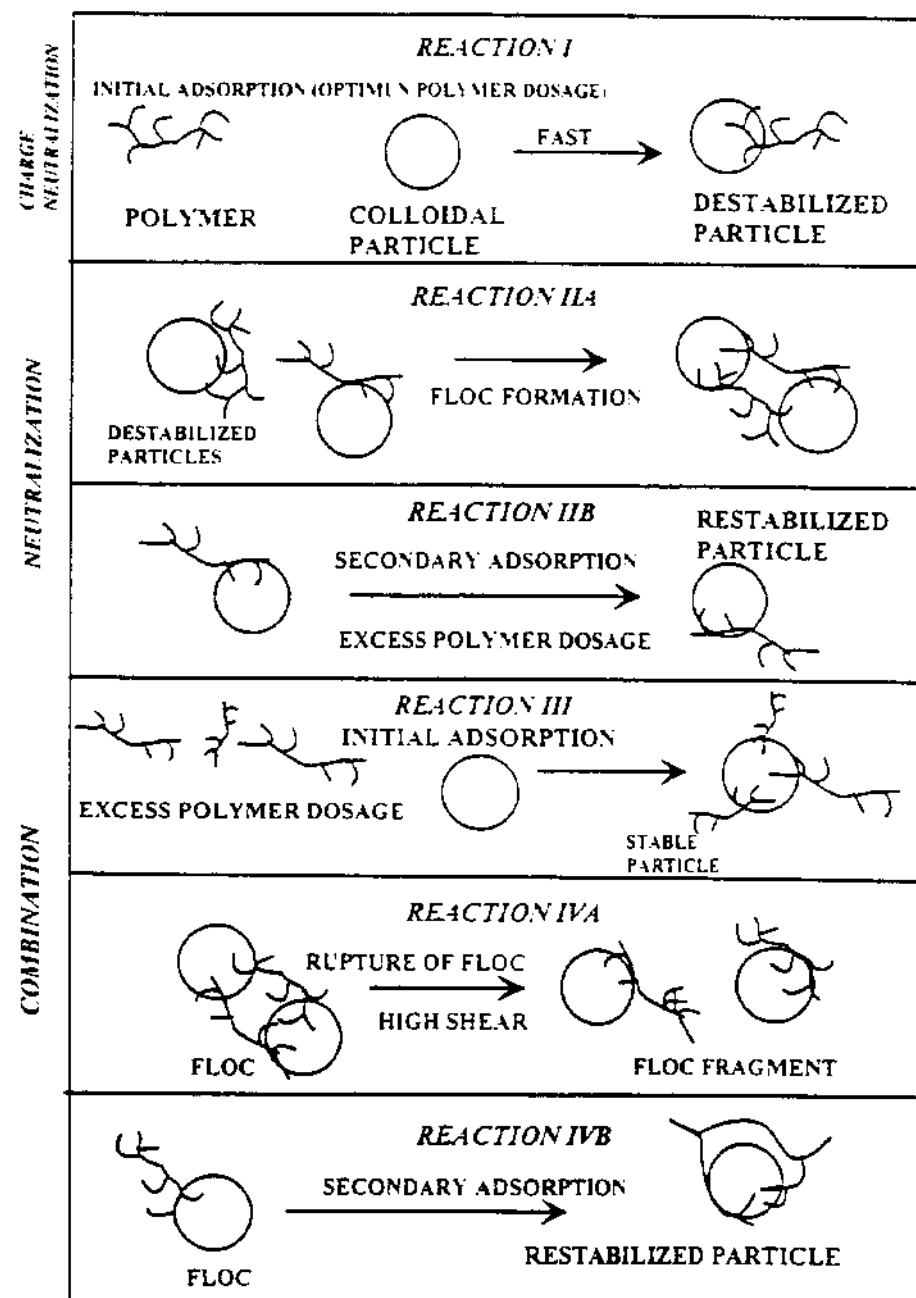
tification of practical methods to control crust development are significant management issues. The addition of an organic material to the soil has proven effective in improving structural stability. On surface irrigation soils containing significant silt and clay contents are highly susceptible to crusting. As a result there is increasing interest in the possible use of synthetic soil conditioners to decrease crust development and improve structural stability and infiltration rates.

When applied in irrigation water, low rates of water soluble polymer can be effective (Wallace and Wallace 1986). In a field test with potatoes in the State of Washington a water soluble polymer was applied at 13 ppm with a center-pivot irrigation system to a 75-ac sandy loam soil and in 1 in. of water (Wallace and Wallace 1990). Gypsum was also applied. The application was just after planting and before any other irrigation or rain so that the cultivated soil could be stabilized by the water soluble polymer. The results of the test were outstanding. The potato vines remained green for about one month longer in the water soluble polymer-treated than in the control. The yield of potatoes was about 25% greater in the treated portion (63.0 vs. 79.3 tons/ac).

Water soluble polymers do not create aggregates when applied to soil, but they can stabilize existing aggregates if the aggregates are fully saturated with a solution of water soluble polymers and if there is a curing-drying period after the saturation. Anionic water soluble polymers can attach to negatively charged clays if a binding agent such as calcium is present. Aggregates that have been stabilized do not reaggregate after they have been crushed. Low solute water can result in failure of stability of soil aggregate.

Clays were attached to anionic polymers more easily when salts were present in solution. With anionic polymers, flocculation was easier and more complete. When polysaccharides are present with anionic polymers in solution, fixation was also easier and more complete. Khamraev et al (1983) reported that clay fixation is best achieved for 30% anionic charges.

Figure 1. Illustration of the process involved in chemical bridging.



### Coagulants and Flocculants

Great quantities of colloidal particles remaining in suspension due to the stabilizing conditions that exist between electrostatic forces on the particle and gravitational forces. Coagulants and flocculants refer to settling in which dilute solutions of particles coalesce together forming particles of large mass and hence higher settling velocities. According to Evangelow et al., 1981. The degree of flocculation depends on the opportunity for particle contact, the depth of the sedimentation, velocity gradients, concentration of particles, particle size, and particle forces which cause the particles to repel each other.

In order for flocculation to occur, the particles must be destabilized and brought together to allow contact and flocculation.

The chemical bridging theory proposes that a long chain polymer with ionizable groups can attach itself to the surface of the colloidal particle at one or more absorption sites (figure 1). Due to its length, the polyelectrolyte will extend beyond the diffuse layer into the solution. This extension can thus be attached to vacant absorption sites on other colloidal particles causing coagulation and flocculation (Tapp et al., 1981).

## Materials and Methods

A Plano silt loam soil was used to evaluate twenty-two water-soluble polymers (anionic, cationic and non-ionic). Soil samples for testing polymers were air dried. Polymers were tested at a concentration of 0.001% (10 ppm). Samples of 0.25 g of each polymer were diluted in one liter of distilled water to obtain a concentration of 0.025% (250 ppm). Forty mm from the stock concentration were diluted in one liter of water to obtain a concentration of 0.001%. This concentration was utilized on both testing methods, sieving and sedimentation tests.

### Aggregation and Stability

Twenty-five grams of air-dried Plano silt loam soil were mixed with water-soluble polymer at a concentration of 0.001% (10 ppm). A minute later, after mixing with the polymer, the mixture was wet sieved through an opening of 500, 250, 125 and 53 micrometers (m) sieves for the first test and 1 mm, 500, 250, 125 and 53 micrometers (m) sieves for the second test. The amount of soil retained for each sieve was oven dried at 42.0°C, and weighed to obtain the weight of soil retained on each sieve. In addition, a base sample (control) was taken by using soil and water only. Both control sample and solution containing polymer and soil were repeated six times.

### Determination of Settling Rates

The sedimentation method is based on the fact that the velocity of sedimentation is a function of soil particle size. Two liters of water and polymer at a concentration of 0.001% were placed in a cylinder (2.6 ins. diameter and 24 ins. long). A control sample was tested using water and soil only. 100 g of soil was poured in the cylinder containing the mixture of water and polymer. The cylinder was inverted several times in order to get a good mixture of the soil with the solution. Samples of 30 mL were taken from a distance of 18 in. from the free surface of the cylinder with intervals of 0, 5, 15, 30, 45, 60, 120, 180 and 300 sec (0, 5, 15, 30, 45, 60 sec and 2, 3 and 5 min respectively).

Table 1. Retention, % of soil particles on sieves of different size openings with applications of different soil binders to a Plano Silt Loam at 10 mg/L.

| SIEVE OPENINGS IN mm |             |             |             |             |              |                  |
|----------------------|-------------|-------------|-------------|-------------|--------------|------------------|
| TREATMENT            | 500 $\mu$ m | 250 $\mu$ m | 125 $\mu$ m | 53 $\mu$ m  | IONIC CHARGE | MOLECULAR WEIGHT |
| CONTROL              | 80.7        | 18.19       | 5.66        | 4.38        |              |                  |
| C-640                | 80.7        | 7.1         | 8.2         | 3.9         | anionic      | 5 M              |
| C-642                | 78          | 11.5        | 6.6         | 3.8         | cationic     | 5 M              |
| C-646                | 78.6        | 10.7        | 6.30        | 4.4         | cationic     | 22 M             |
| C-648                | 80          | 11.3        | 6.5         | 2.1         | cationic     | 22 M             |
| C-650                | 82          | 10.3        | 4.3         | 3.4         | cationic     | 25 M             |
| P-0874               | 81.3        | 10.9        | 5.8         | 1.8         | cationic     | 8 M              |
| P-0805               | 72.7        | 13.2        | 9           | 4.8         | cationic     | 5 M              |
|                      | 70.8        | 2.6         | 0.2         | 0.14        | anionic      | 15 M             |
| C-602                | 75.9        | 15.3        | 6.8         | 1.9         | anionic      | 16 M             |
| P-0843               | 72.1        | 21.8        | 5.6         | 0.4         | anionic      | 15 M             |
| P-0824               | 83.6        | 11.7        | 4.1         | 0.4         | anionic      | 8 M              |
| C-634                | 78.4        | 12.8        | 6.8         | 1.9         | anionic      | 17 M             |
| P-0811               | 78.7        | 14.         | 5.6         | 1.1         | anionic      | 15 M             |
|                      | 74          |             |             |             |              |                  |
| C-878                | 86.2        | 7.6         | 4.3         | 1.8         | ADHESIVE     |                  |
| C-877                | 86.5        | 6.4         | 4.5         | 2.4         | ADHESIVE     |                  |
| P-1809               | 88.3        | 6.4         | 3.1         | 1.9         | cationic     | 250K             |
| P-1807A              | 87.9        | 6.3         | 4.4         | 1.2         | cationic     | 400K             |
|                      |             |             |             |             |              |                  |
| TREATMENT            | 1 mm        | 500 $\mu$ m | 250 $\mu$ m | 106 $\mu$ m | IONIC CHARGE | MOLECULAR WEIGHT |
| CONTROL              | 57          | 20          | 9           | 6           |              |                  |
| 866-A                | 81          | 13          | 4           | 1           | anionic      | 17 M             |
| A-836                | 79          | 12          | 5           | 3           | anionic      | 15 M             |
| WASPAM               | 76          | 16          | 4           | 1           | anionic      | 7                |
| E-4067               | 79          | 14          | 4           | 1           | anionic      | 35 M             |
| E-4068               | 76          | 16          | 4           | 1           | anionic      | 50 M             |

Samples obtained at different time intervals were oven dried (42°C) and weighed to obtain the amount of soil sedimented on each sample. Soil samples treated with polymer solution and with water were repeated six times.

### Determination of Infiltration Rates

700 g of Plano silt loam soil were placed in a cylinder 12 ins. in length and 2.5 ins. in diameter covered by a double screen to retain the soil. The 700 g samples, 6 ins. in length and 2.5 ins. in diameter, were saturated with water and with polymers selected with a solution of 10 mg/l. The soil samples were saturated from the bottom to the top and left over a period of 24 h to drain. These procedures were followed for the two selected polymers.

The cylinders containing the treated soil samples were tested for water infiltration. The infiltration of 500 ml of water at different time intervals were recorded (time for the first drop, 5, 10, 15, 30, 60, 120 min and 24 h). Each test consisted of three cylinders, replicated three times. The soil samples were prepared from 50% aggregates retained in a 4 mm opening sieve and 50% retained in a 2 mm opening sieve. Similar tests were performed on a 100% sample of aggregates retained in a 2 mm opening sieve.

A final test was performed on similar soil samples to test the effect of calcium salt in the stability of aggregates. A solution containing 10 mg/l of polymer, 10 mg/l of calcium carbonate ( $\text{CaCO}_3$ ) and 40 mg/l of citric acid was applied to the cylinder

with the soil. The infiltration of 500 ml of water at different time intervals were recorded (time for the first drop, 5, 10, 15, 30, 45, 60 and 120 min). Each test consisted of three cylinders, replicated three times as above.

## Preliminary study

Many water soluble polymers are commercially available today. In order to determine which polymers to use in this research a preliminary screening of approximately 150 polymers was conducted. Selection was based on stability of aggregates and percentage of retention of soil on sieves of different openings. A second test was the settling rates based on the fact that the velocity of sedimentation is a function of the soil particle size. Based upon the laboratory results, five polymers were selected for further study on a laboratory test. From these five polymers only two were tested on commercial applications. In our preliminary tests we found that the anion charges greater than 30% were more effective and that the greater the atomic weight and thus the greater the polymer chain length, the more effective the polymer was in stabilizing the soil particles and aggregates.

## Results and Discussion

A statistical analysis was performed for mean, standard deviation and confidence interval; however, the discussion herein will be based on the data obtained from weighing of the oven-dried soil samples. Two polymers, P-0841 and C-636, do not dissolve completely when diluted with water. They formed small clots. The first set of data obtained was based on sieves of 500, 250, 125 and 53 m. The second set of data was obtained for sieves of 1 mm, 500, 250, 125 and 53 m.

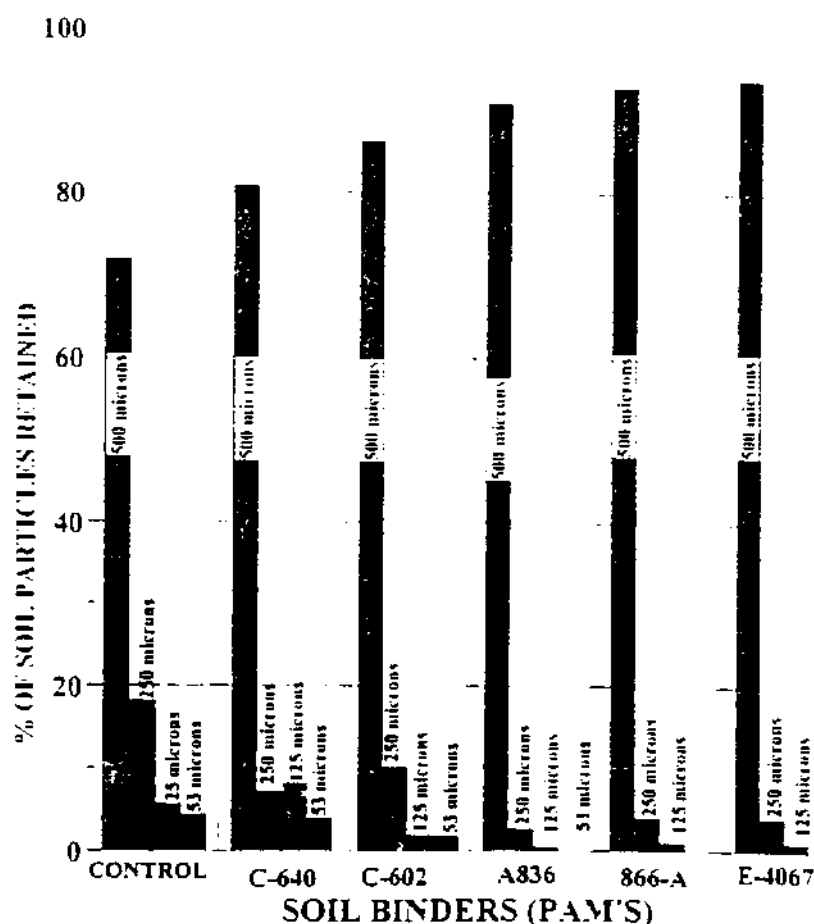
### Aggregation and Stability

Table 1 shows the average, in percentage of soil retained, for each sieve and the ionic charge of each polymer tested. When compared with the results obtained with the control (72.8% of soil retained on the opening sieve of 500 m), the highest percentage of retention (aggregation) occurred on

Table 2. Average of soil mass flocculated at 18 ins. depth obtained in g/100 cc at different settling times.

| Flocculated Plano silt loam in g/100 cc |      |           |           |            |            |            |
|---|------|-----------|-----------|------------|------------|------------|
| CLARIFIER                               | T °C | 0 seconds | 5 seconds | 15 seconds | 30 seconds | 45 seconds |
| CONTROL                                 | 22.5 | 1.2       | 4.2       | 3.0        | 1.96       | 1.2        |
| P-0843 (-)                              | 22   | 2.5       | 1.5       | 0.07       | 0.02       | 0.02       |
| P-0824 (-)                              | 24   | 2.0       | 0.1       | 0.05       | 0.02       | 0.02       |
| C-602 (-)                               | 25   | 3.8       | 4.2       | 0.44       | 0.03       | 0.02       |
| P-0841 (-)                              | 25   | 4.1       | 2.3       | 0.12       | 0.06       | 0.01       |
| P-0811 (-)                              | 28   | 3.7       | 1.8       | 0.09       | 0.03       | 0.01       |
| C-623 (-)                               | 22.5 | 1.5       | 4.7       | 2.02       | 0.2        | 0.1        |
| P-1809 (+)                              | 25   | 2.7       | 3.3       | 2.41       | 1.50       | 1.02       |
| C-877 (adh.)                            | 25   | 2.4       | 5.4       | 2.07       | 1.82       | 1.56       |
| C-878 (adh.)                            | 24   | 2.4       | 4.4       | 2.51       | 1.57       | 0.98       |
| C-634 (-)                               | 23   | 3.4       | 2.7       | 0.50       | 0.17       | 0.10       |
| 866A                                    | 25   | 7.2       | 6.0       | 2.43       | 1.23       | 0.04       |
| WASPAM                                  | 22.5 | 5.5       | 3.7       | 1.30       | 0.43       | 0.17       |
| A-836                                   | 25   | 5.9       | 6.3       | 1.00       | 0.27       | 0.10       |
| E-1266                                  | 15   | 5.5       | 5.2       | 2.70       | 0.57       | 0.03       |
| I-8051                                  | 26   | 4.6       | 4.1       | 2.33       | 0.87       | 0.03       |
| E-4067                                  | 25   | 6.0       | 4.3       | 0.67       | 0.13       | 0.07       |
| E-4068                                  | 25   | 4.0       | 4.1       | 2.43       | 0.23       | 0.07       |
| CONTROL                                 | 26   | 3.1       | 4.2       | 1.43       | 2.60       | 1.00       |

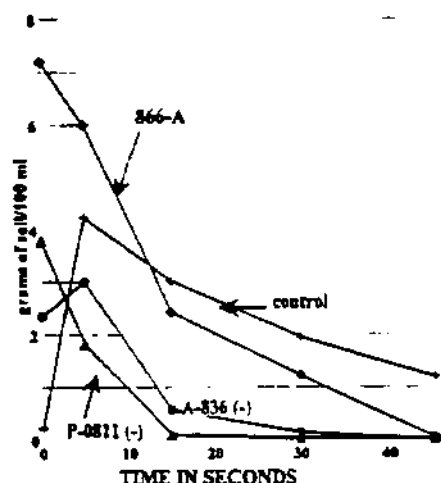
Figure 2. Retention, % of soil on particles of different size openings with application of soil binders to a Plano Silt Loam at 10 mb/l.



the 500 m sieve opening with the polymers A-836 (96.8%) C-632 (93.2%). Table 1. Both of the polymers have a negative ionic charge.

The P-1809, P-1807A, C-877, C-878, P-0824, C-650, P-0874 C-640, and C-648, obtained values of 88.3, 87.9, 86.5, 86.2, 83.6, 82, 81.3, 80.7 and

Figure 3. Suspended solids removal by flocculation settling on a Plano Silt Loam at 10 mg/l.



80, respectively. The other polymers gave values less than 80.0%

Table 1 shows the average, in percentage of soil retained, for each sieve for the second group of data. For this group of sieves (1 mm) two polymers, the 866-A and the 836-A formed stable aggregates to dispersion and at the 1 mm sieve were retained 81 and 79 % respectively.

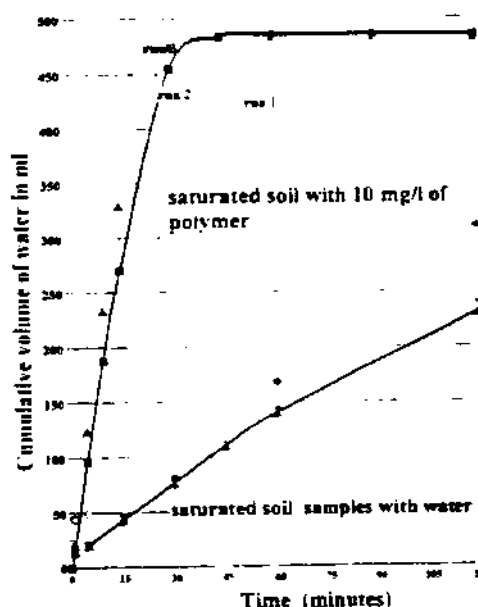
### Determination of Settling Rates

Table 2 shows the average of soil obtained for each interval of time during the settling of soil particles after mixing with a solution of polymer at a concentration of 0.001%. Also the variation of temperature (maximum and minimum) for each polymer tested is presented. By comparison with the results obtained with the control, best results were obtained with 866-A, A-836, E-1266, E-4067 and E-4068.

Polyacrylamides tested with the sedimentation test differ from one another in time and speed for aggregating the soil particles. According to the graphs (settling rates graphs are presented) solutions with 866-A, A-836, P-18041 and P-1811 aggregated and sedimented the soil particles immediately when the soil was poured in the solution (time=0 sec) and 866-A, A-836, E1266, E4067, WASPAN and P-0843, needed 5 sec ( $t=5$  sec) for beginning to aggregate the soil particles. After the 5 sec., the process of sedimentation occurs faster and for a relatively short period of time.

The discussion presented here, as was mentioned above, is based on the

Figure 5. Effect of polymer (866-A) on infiltration rates into 2 mm size aggregates.



data obtained when carrying out the sedimentation test. The sedimentation test for each polymer was repeated six times. Thus, the conclusions based on this preliminary data are just a guideline for further investigations.

The results obtained in the sieving test (aggregation and stability) were used to decide which polymers should be tested with the sedimentation test. Considering the previous results only 17 polymers were tested (all those with negative charges). Only four polymers, 866-A, A-836, E-4067 and WASPAN, are consistent for both sieving and sedimentation tests. For the other polymers, the data obtained differs from one test to another.

The polymers A866, A-836, E4067 and WASPAN which were consistent in the aggregate stability and sedimentation test will be tested in the field. The field test studies the binding effectiveness of PAMs in construction site application and the ability of polymers to inhibit soil erosion. The field study will determine their impact on the K and CP components of the Universal Soil Loss Equation (USLE) so the effects on soil loss using polymers can be quantitatively determined.

### Determination of Infiltration Rates

The results of the tests are presented in figures 4 to 9. The volume of water without soil conditioner in-

Figure 4. Effect of polymer (866-A) on infiltration rates into 4 mm size aggregates.

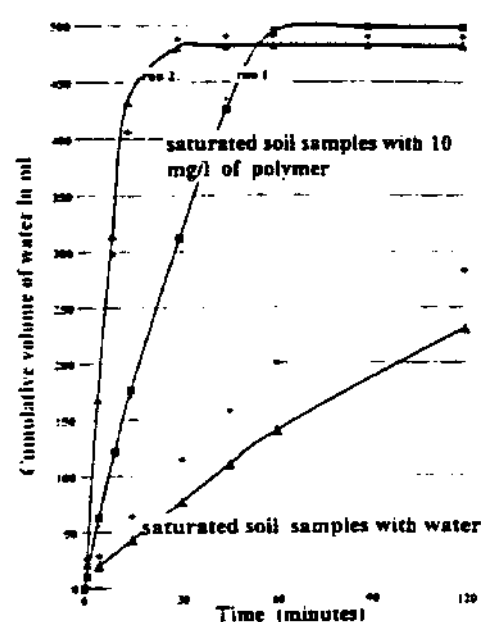
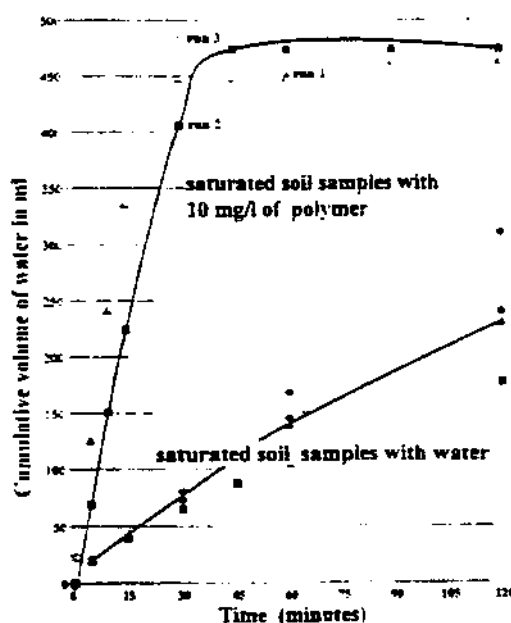


Figure 6. Effect of polymer (I-836) on infiltration rates into 4 mm size aggregates.



filtrated at the 120 min. mark averaged 231 ml or 115 ml/hour. After 120 min the infiltration effectively stopped and at 24 h the volume of water infiltrated remained the same. Figure 4 compares the discrete and cumulative rates of infiltration for a soil sample without any soil conditioner to that with 10 mg/l of polymer 866-A. The increment of water infiltration is double that of the untreated soil at the 120 min. mark (figures 4 and 5). The total volume of the infiltrated water averages 490 ml

Figure 7. Effect of polymer (886-A) with citric acid on infiltration rates into 4 mm size aggregates.

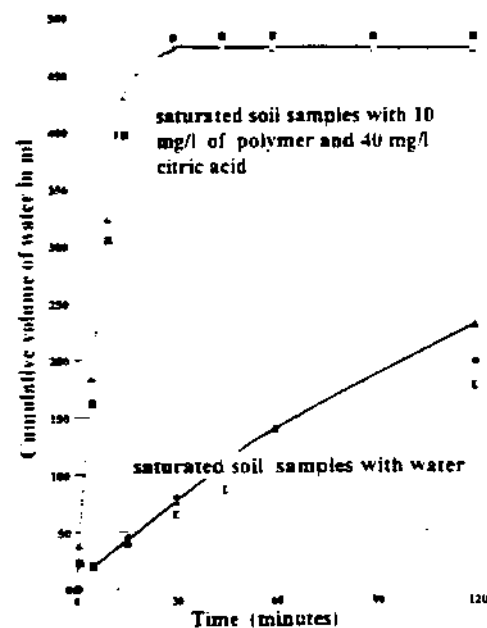


Figure 8. Effect of polymer (A-836) with citric acid on infiltration rates into 4 mm size aggregates.

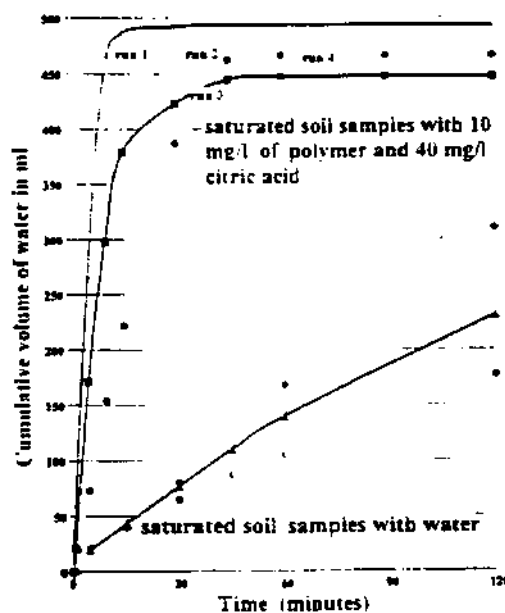
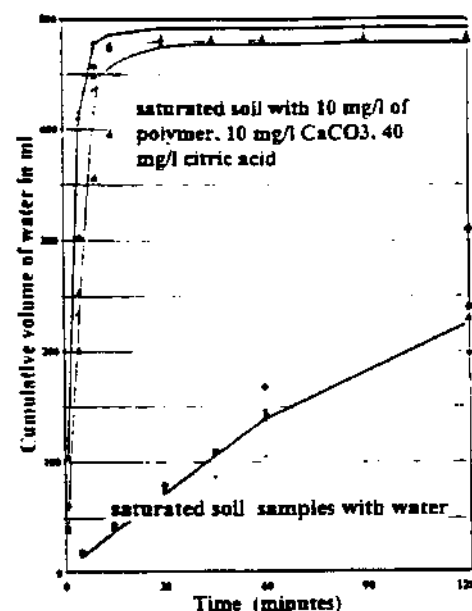


Figure 9. Effect of polymer (866-A) with citric acid and calcium carbonate on infiltration rates into 4 mm size aggregates.



(245 ml/hour) or 98% of the volume of water to be infiltrated.

The soil conditioner changed the infiltration capacity of soil samples. The mean infiltration volumes were different than the control or untreated sample. The infiltration volumes at each time interval were used. The samples, control and treated, were carried to saturation. This soil moisture condition was considered to be saturated flow. These results to date suggest that applications of soil conditioners can have a beneficial effect on soil conservation, by maintaining an improved soil structure and higher infiltration capacity of silt loam soils. This illustrates the increase in aggregate resistance to disintegration, slaking, soil crust formation and the reduction of erodibility.

Figure 5 shows that the infiltration rates into smaller 2 mm size aggregates do not change significantly from the infiltration rates into the larger 4 mm size aggregates.

The samples were infiltrated with polymer free water after one single application of the soil conditioner. The results seem to indicate that the polymers studied in the laboratory which have higher molecular weight and higher percentage of anionic charge are more effective than the polymers now used in irrigation. This suggests that for construction site erosion one application may be enough

until the grass cover protects the soil. Figures 6 and 8 present the results of infiltration of A-836, a polymer widely used in irrigation. The results indicate that soil conditioners such as 866-A with higher molecular weight and higher percentage of anionic charge are more effective for construction site erosion than the ones now used for irrigation.

Figures 7 and 8 suggest that the combination of citric acid with the polymer performs more consistently than the polymer alone. The combination with citric acid makes the polymer more effective, suggesting that the amounts of polymer can be reduced, making the polymers more cost effective for construction and possibly also for irrigation.

Figure 9 presents the results of the soil samples treated with a solution containing 10 mg/l of polymer, 10 mg/l of calcium carbonate ( $\text{CaCO}_3$ ) and 40 mg/l of citric acid to study the chemical bridging effect of anionic polymer soil conditioners with calcium salts. The data suggest that anionic soil conditioners at a concentration of 10 mg/l with the addition of calcium salt has a major influence on the increase in aggregate stability and reduction of erodibility by binding the polymer to the soil.

The effect of calcium is related to the charge density of the colloidal particles and the anionic nature of the

soil conditioner (figure 1). The addition of  $\text{CaCO}_3$  and citric acid changed the infiltration capacities of the soil samples treated. The volume infiltrated was twice the rate of the sample treated with the soil conditioner alone, and four times larger than the control.

## Conclusions

The data shows that five polymers were consistent for both the stability and sedimentation test. Polymers with a negative (anionic) charge gave better results than polymers with a positive (cationic) charge for the sieving test (stability).

The results of the various tests indicate that simple laboratory procedures can be used to help guide field application of synthetic soil conditioners (water soluble polymers).

The results indicate that the new water soluble anionic polymers with higher molecular weight ( $8 \times 10^6$  or greater) and greater than 15% active sites are the most effective at rates of 0.001%.

The stability of the aggregates increases with the treatment of PAMs. PAMs at the rate of 10 mg/l or 0.001% had a profound effect on the particle size distribution and the aggregate resistance to dispersion.

Results suggest that soil conditioner decreases the runoff and has a

beneficial effect on soil conservation and soil structure on erodible soils and can improve infiltration. The increase in infiltration may lead to less runoff and more plant available moisture. Soil conditioners are a cost effective practice in construction sites, where we are lacking a practical solution to an ever present problem.

## Future Study

The future study is to evaluate and demonstrate the use of PAMs for controlling erosion and sediment loss from critical sites in rural Wisconsin. Critical sites are defined as those areas which, because of their location or land use, produce a high sediment load on receiving waters. In addition to the ability to control erosion, PAMs will be evaluated on cost, ease of application, reliability and effects on plant emergence and growth.

Soil binders (PAMs) which fit the above criteria are perfect candidates for preventing soil loss, stabilizing grass waterways and binding manure to soil.

The study also will include the research of soil erosion inhibitors to determine their impact on the K and CP factor of the Universal Soil Loss Equation (USLE) so the effects on the USLE using polymers can be quantitatively determined. The study will test the binding effectiveness of

PAMs in manure field applications and the ability to clarify animal waste to reduce liquid volumes while preserving the high fertility value of manure.

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